Single Ion Implantation with Scanning Probe Alignment

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Single ion implantation is a "top down" path to the formation of single atom devices [1]. An example of proposed single atom devices are impurity spin based quantum computers were information is encoded in the electron and nuclear spins of individual atoms in arrays aligned to control gates and readout Single Electron Transistor (SET) structures [2]. We present results from our development of a single ion implantation technique integrated with a scanning force microscope. Accurate alignment at the 5-10 nm level is a crucial requirement for reliable single ion placement. We address this through integration of the ion beam with a scanning probe tip containing an aperture. Figure 1 shows the conceptual layout of the approach. The piezoresistive Scanning Force Microscope images non-destructively the device region to be implanted in a high vacuum chamber (base pressure 10^{-8} torr) [3]. Following imaging, sites for implantation are selected, and ions are allowed to reach the probe tip. The probe tip is pierced with a hole, allowing it to transmit ions at a rate of a few Hz. Secondary electron bursts from the impact of individual highly charged dopant ions (e. g., $^{31}P^{13+}$) are detected in a scintillator coupled to a photomultiplier tube. Pulse heights from detection of multiple electrons from one highly charged ion impact are well separated from single electron background events. Secondary electrons are guided to the detector with electrical and magnetic fields, so that the probe tip can be held in close proximity (<1 μm) to the sample. Following each ion impact, the beam is blanked within a few μs, and the process of imaging and alignment is repeated. Ion arrival times at the tip are random, but the transmission rate is small enough to ensure that only one ion impinges on a designated area before the beam is blocked. The diameter of the hole in the scanning probe tip limits the minimum achievable placement accuracy, so we have developed a technique for nm-scale hole formation. Hollow pyramid tips (Figure 2) on piezoresistive cantilevers are mounted on Si_3N_4 membranes. Using a low divergence, highly focused ion beam in a conventional FIB, we drill 1 μm size holes through both the tip and the membrane. The hole in the tip is then reduced in diameter by local, electron beam assisted deposition of Pt or TEOS oxide. The hole in the membrane is aligned to the hole in the tip and pre-collimates the implant beam. In Figure 3, we show data from ion transmission measurements through aligned holes with a tip opening of 250 nm. In our presentation we will discuss resolution requirements for dopant spin based single atom devices with respect to the capabilities of scanning probe aligned single ion implantation.

References

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Acknowledgments: We thank F. Ogletree for stimulating discussions, and the staff of the UC Berkeley Microlab, and the National Center for Electron Microscopy for their technical support. This work was supported by NSA and ARDA under ARO contract number MOD707501, and by the U. S. DOE under contract No. DE-AC03-76SF00098.

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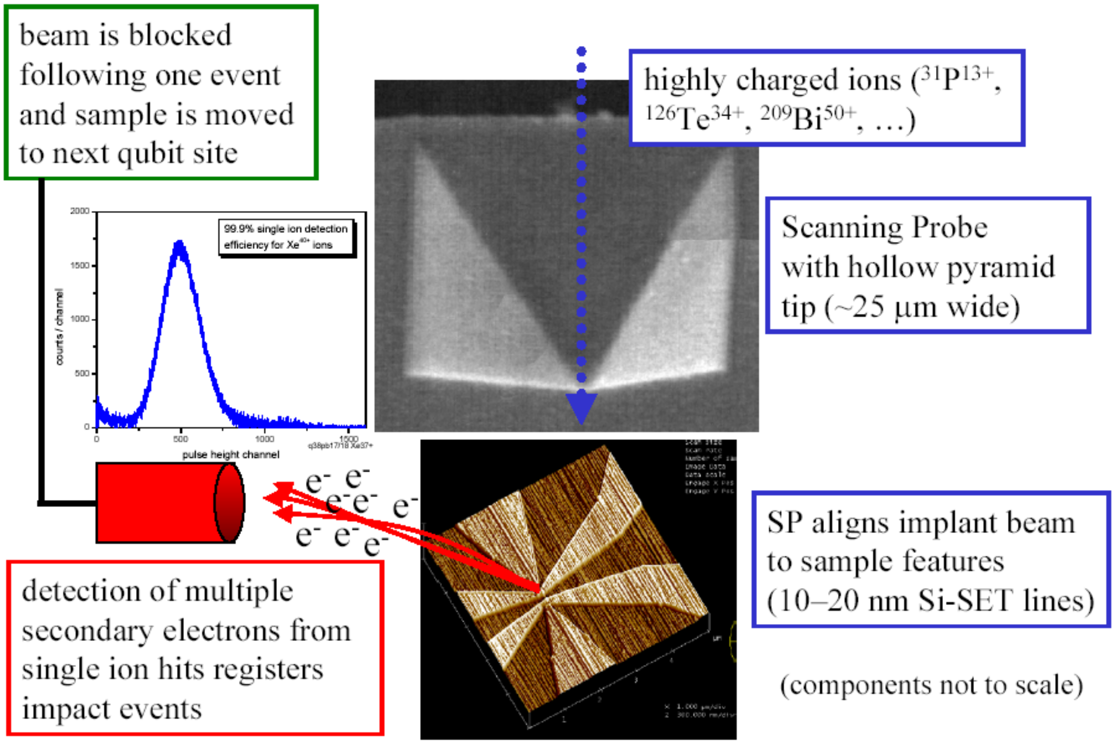

Figure 1: Conceptual layout of the setup for single ion implantation aligned with a scanning force microscope.

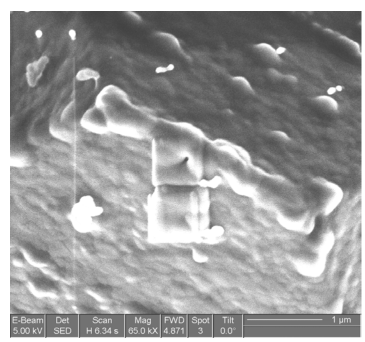

Figure 2: (left) Hollow silicon nitride pyramid probe tip. (right) Tip with holes, one covered with a patch of Pt, while the diameter of the remaining hole is reduced to 30 nm by Pt deposition.

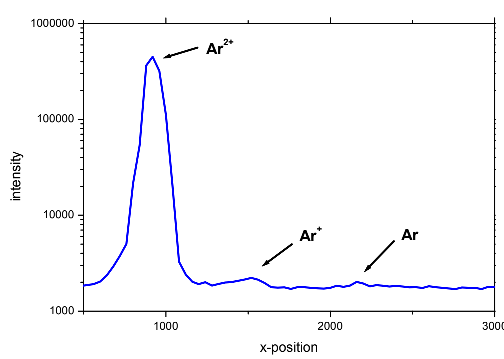

Figure 3: Results from charge state analysis of Ar^{2+} ions (E=7.2 keV) transmitted through aligned holes in tip and membrane with a tip opening of 250 nm. Over 99 % of ions transmit the tip without charge exchange.